National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No. NAS-5-12487

ST-SP-GM-10605

CONTRIBUTION TO THE STUDY OF THE RELATIONSHIPS BETWEEN SOLAR AND GEOMAGNETIC ACTIVITIES

by

B. Bednárová-Nováková

(Czechoslovakia)

7

(French)

11 MAY 1967

ST-SP-GM-10605

CONTRIBUTION TO THE STUDY OF THE RELATIONSHIP BETWEEN SOLAR AND GEOMAGNETIC ACTIVITIES*

Journal of Atmospheric and
Terrestrial Physics,
Vol.29, pp. 377-384,
Perg.Press (No.Ireland), 1967

by B. Bednářová-Nováková
(Czechoslovakia)

ABSTRACT**

The article states the necessary conditions under which geomagnetic storms arise, as revealed by observations of the Sun. The new criteria do not conflict with those previously developed, based on other phenomena.

On the strength of these new ideas a method for forecasting geomagnetic activity has been elaborated, enabling a sudden commencement to be predicted with great accuracy. It makes possible the forecasting of geomagnetic storms in each period of the solar cycle, and to say in advance whether the onset of a given storm will be sudden or gradual.

As examples for the purpose of explaining their origin, use has been made of the SC-geomagnetic storms of 11 February 1958, 20 September 1959, 29 October 1963 and 22 November 1963. Except for the first, all these storms had been predicted on the basis of observations of the Sun by means of the spectrohelioscope. Furthermore, an explanation is given of the origin of the gradual-onset geomagnetic storm of 6 and 7 October 1960, which had likewise been predicted. On the same principles explanations are given of the geomagnetic quiet period of 19–25 June 1965, which recurred six times (16–17 July, 13 August, 8–9 September, 6–7 October, 1–3 November and 28–29 November 1965) and of the one that occurred twice – on 31 December 1965 and 1 January 1966, and on 27–28 January 1966.

*
* *

The new concepts, at which the workers of the Geophysical Institute of the Czechoslovakian Academy of Sciences have arrived on the basis of careful studies of solar situations prior to every geomagnetic storm, depart appreciably from those currently recognized amongst specialists. However, they are based upon a systematic and detailed observation of solar activity and are moreover confirmed by exact forecasts.

---

* Contribution à l'étude des relations entre les activités solaire et géomagnétique.

** Author's abstract. (The original paper is written in French)

Starting from the Sun, we have noted that an Earth-oriented coronal formation is absolutely prerequisite for the onset of a geomagnetic storm or disturbance. This condition has been recognized as a result of spectrohelioscopic observations of the Sun, and also owing to the compilation of dates and various other indications in this field, assembled during a long continued international cooperation. It is as valid for the solar activity maximum, as for the minimum periods. The condition itself responds to a certain degree to the results obtained in this domain by such specialists as Allen (1944), Kiepenheuer (1953), Vsekhsviatsky (1963), who calculated with the accounting for the liberation of corpuscular radiation from the solar corona. This condition is not in contradiction with the hypotheses put forth by theory specialists. Chapman considers that the corona extends to the Earth, Parker speaks of coronal plasma expansion in interplanetary space. In order to give a better explanation the relationships existing between the Sun and the Earth, Pecker (1961) stated that "the chromosphere and the corona play in them an essential part". This, incidently, responds even to the results registered by means of Earth's artificial satellites, from which it stems that coronal plasma spreads to a distance greater than that between the Sun and the Earth, i. e., in other words, that it fills more or less the whole interplanetary space. The contribution consists in that the condition, which we have established, determines exactly and before anything else, the moment of time when the more or less condensed coronal plasma reaches the Earth's magnetosphere. If it is not satisfied, no geomagnetic disturbance, however small, may set in: under the circumstances, we witness the geomagnetic quiet. Both these cases can assuredly be recognized in advance by the observation of solar situations on the CM.

It is generally known that the existence of coronal formations, as well as their shape and direction depend on the disposition of local magnetic fields as well as that of the general magnetic field of the Sun. It would thus suffice for the establishment of forecasts, to observe the corona and to determine its formations above the CM, which is, however, unrealizable from ground observation stations. It would be possible to perform these observations from an artificial planet moving over the Earth's orbit, but removed from the latter by 90° (that is, with an advance or lag of 90°) into a position such that it would be possible to encompass, photographically or in any other fashion, the entire profile of the corona in the plane of the CM. Another method to be considered would be that of direct measurement of magnetic fields in the chromosphere and the corona above the CM, and of determination of the spots, where substantial field changes have occurred. This procedure is, however, a little too long and too slow, and furthermore not always realizable. It is not excluded that the observation of the fields in the chromosphere and corona in a manner analogous to that adopted by Ness and Wilcox (1966) at the basis of measurements by means of artificial satellites would prove to be useful.

However, there still exists another, indirect but very precise method, which assures absolutely certain results. It is based upon the study of monochromatic images observed in the spectral line H_α. Indeed, it has been established that the chromospheric structure, filaments, surges and faculae constitute not only excellent indicators of magnetic field disposition, but also provide in a very detailed and rapid fashion the information relative to any change in the respective layers, that is, the chromosphere and corona.

---

* CM stands for "central meridian"; PCM - for passage of CM.

They thus inform us also of any changes taking place in the corona and in the disposition of coronal formations. Most of these changes are sudden and of more or less brief duration. Of this it is easy to be convinced by merely studying the relationships existing in the chromosphere, the filaments and the corona, photographed at time of eclipse of the Sun.

The new method of forecasting the geomagnetic activity, which consists precisely in the observation of the chromospheric structure and filaments, is extremely simple and accurate, but it requires a thorough observation of the solar activity in every respect. Its accuracy, as well as the exactitude of the new concept on the relationships between the solar and geomagnetic activities are best proved by the forecasts conducted at the Prague Geophysical Institute with success as early as from 1959.

In the following we shall deal with some solar situations having preceded the geomagnetic storms: we shall point to specific examples, of which the analysis will allow us to provide the explanation of the new hypotheses put forth in regard to the substance of relationships between the Sun and the Earth in the field of geoeffective corpuscular radiation.

Three principal situations preceding the onset of geomagnetic storms were noted: 1) the phenomenon of sudden disappearance at the center of the disk, 2) the presence of a center of activity at the center of the disk, when there is a certain degree of change in the local field, 3) the absence of local magnetic fields at the CM and the presence of a free filament.

SUDDEN DISAPPEARANCE OF FILAMENTS

The phenomenon of sudden disappearance at the center of the visible solar disk is always followed by a SD-geomagnetic storm. As the filaments are nothing but the accumulation of hydrogen masses around the lines of force of local magnetic field, the disappearance of filaments implies to a certain degree the annulment of the field in the given layer of the chromosphere or of the corona. One may speak in terms of compensation or neutralization of the field, and so forth. Since it has been noted that various types of coronal formations exist above different types of prominences, one may assume at time of change in the type of prominence also a change in the coronal formation. As was proved by the studies of solar corona photographed in the course of total solar eclipses, special coronal currents correspond to eruptive or active prominences (Bednářová-Nováková, 1961). The existence of these currents has been confirmed by Vsekhsviatsky and Bugolavska (1939, 1949) namely in connection with flocculi. Thus it seems that during fliament's disappearance, or even prior to it, a coronal current is formed, which is eventually composed of different formations with shape of rays, etc. Thus, hydrogen masses penetrate eventually into the higher layers of the corona, where their complete ionization takes place. Judging from the different altitudes at which the disappearance of the prominence took place, the height, at which the complete ionization of hydrogen masses took place, varies, for example, as a function of the momentary temperature of the different corona layers, etc.

The influx of new particles is translated by a certain condensation of the coronal plasma. If these phenomena take place above the center of the solar disk, the condensed coronal plasma reaches the Earth's magnetosphere, which has for effect the onset of a SC-geomagnetic storm. Its intensity depends on the degree of coronal plasma condensation, and this degree naturally can not be determined with sufficient precision in advance. It is nevertheless possible to predict, on the basis of the character of changes and also at times depending upon the magnitude and eventually the density of the filament, whether we are to be confronted with a powerful storm or only with a weak disturbance. The SC moment may however be established with a relatively great accuracy. Some typical examples of SC-storms that took place under such conditions are evidence of the exactitude of the new hypotheses put forth with regard to relationships between the Sun and the Earth: these are, for example, the storms of 11 February 1958 and of 20 September 1959, both described in literature (Bednářová-Nováková, 1959, 1961). Prior to these SC-storms, filament disappearance took place at the center of the solar disk. Prior to the storm mentioned at first , the DB was observed on 9 February 1958 at Meudon. The second storm was forecast in our area on the basis of DB observation at the center of the disk on 19 September 1959. The SC was foreseen for 20 September between 1100 and 1200 hours U.T., and took place effectively at 1157 hours U.T. (Bednářová-Nováková, 1965).

THE CENTER OF ACTIVITY

The presence of a center of activity at solar disk's center, with surges and filaments that change abruptly and disappear to eventually reappear again, is very often followed by a SC-geomagnetic storm. In this case too, one must foresee the existence of a coronal formation, newly formed and directed at the Earth. The example of this is in the storms of all periods and also those of the epochs prior and during the solar activity minimum.

The SC-storm of 29 October 1963 should be placed in this category; it took place after the PCM by the spot group (E37, E22, D17) during the days from 24 to 28 October 1963. The SC is connected with the passage of CM by the eastern edge of the vast magnetic field of that center of activity, where the intensity was already lesser. Thus, at time of great changes there much rather took place a neutralization of the magnetic field in the respective layers. Another storm of same kind took place on 22 November 1963 after the passage of CM (A 3), the latter having taken place on 21 November 1963.

Here, as on the above-mentioned case, we have witnessed the onset of a coronal formation directed toward the Earth, so that the coronal plasma could have penetrated to the proximity of the Earth's magnetosphere. In such cases the coronal formation may take the shape of a current or of ray beam; eventually it may be the case of the equatorial wing of corona minimum. In this case, however, this would be a coronal wing formed suddenly, in contrast to a durable coronal formation, to which we still shall refer in the following.

Otherwise, the centers of activity, at disk center as well as anywhere else on the MC, so long as they do not present a suitable activity (that is,

filament disappearance, surges etc.) are followed by period of absolute geomagnetic quiet (Bednárová, 1956). As was demonstrated by the studies of the solar corona, there is formed above such centers structures in the form of arcs in the lower corona, while the upper corona seems to be divided in the direction of the principal polarities of the local field. In this case, the Earth is in a space practically devoid of plasma (we have in mind the plasma emerging directly from the corona). The magnetosphere being surrounded only by a sort of interplanetary "dust" is incapable to generate a geomagnetic storm. This situation was already described by Pecker and Roberts (1955) for the monochromatic corona; they called the space above the center of activity "the cone of the vacuum". These examples are compiled in Table 1, where it is referred to a recurrent action of the negative effect of the local solar magnetic field represented by faculae in which sunspots appeared from time to time.

TABLE 1

Year 1965

Days of Geomagnetic quiet	Solar situations
19 – 25 June	12 – 21 – faculae 22 – 24 – faculae later on (A2)
16 – 17 July	16 – 17 July – faculae
13 August	11 August – (A1) + faculae
8 – 10 September	6 September – faculae 7 – 8 September – (D13 14) at North)
6 – 7 October	6 October – faculae
1 – 3 November	31 October – (A3) + faculae 1 November – (C11)
28 – 29 November	25 – 26 November – (A1) + faculae

TABLE 2

Days of Geomagnetic Quiet	Solar Situation at Central Meridian
31 December 1965 1 January 1966	30 – 31 December 1965 – (C4-C5-J2) South
27 – 28 January 1966 eight times K_p = 00	25 January – (D11) – the passage at MC lasted one whole day

Table 2 shows the dates of appearance of the negative effect, which recurred twice after the PCM by the sunspot group.

ABSENCE OF LOCAL MAGNETIC FIELDS

The absence of local magnetic fields at the central meridian (CM) is linked with the idea of minimum type of corona, such as was, for example, photographed in 1954. In this case the geomagnetic disturbance may occur when one of the equatorial wings (either North or South) is oriented toward the Earth. The conditions exist in this case for the formation of small or moderate geomagnetic disturbances, ascribed in literature to Bartels' M-regions. They are linked with the appearance of free filaments with high heliographic widths, which are characterized by the fact that they exist without the presence of local bipolar fields, manifest at the CM (Bednarova-Novakova, 1960, 1964). If such a field is discovered at the CM, eventually between the filament and the equator at an epoch when the perturbation has already been produced, the latter disappears outright, and is immediately replaced by the geomagnetic quiet, as this was already noted by others, for example, by Waldemeier (1946) and Kiepenheuer (1953).

A certain expansion of the perturbation takes place in the presence of free filaments, which is evidence that in this concrete case coronal plasma condensation takes place after the ionization of hydrogen atoms liberated from the filaments; as assumed by Kiepenheuer (1946), this may occur as a consequence of diffusion. In principle nothing else happens that is not occurring after the disappearance of the filaments and after surges. The coronal plasma must always be assured of the possibility to spread to the proximity of the magnetosphere. The difference consists in that the SC-disturbances take place in connection with the coronal formation process above the center of the disk (respectively above the CM), whereas the so-called M-regions' perturbations and some other irregularities are characterized by the more or less prolonged existence of the equatorial wing of the corona minimum. In this case previous conditions exist for the onset of perturbations with gradual commencement, for here the magnetosphere has been reached by agglomerations of coronal plasma, already somewhat diffused.

It is nevertheless appropriate to recall in this context that the duration of recurrent perturbations is sometimes augmented, generally as a consequence of the preceding perturbation, which is in relation with the passage at the CM of the center, where the activity has attained a certain degree, so as to produce a total or partial neutralization of the field in the corona. And this is also why the recurrent series often have a sudden commencement; this explains also the double connection of the monochromatic corona in the recurrences, as was observed by Bednárová (1954) and Bell & Glazer (1957).

While above centers, with or without spots, it is possible to register in the epoch of accrued activity a certain green coronal line intensity increase; above the calm filaments characteristic of M-regions the intensity of the coronal line remains very weak (Bednárová-Nováková, 1963).

*
* *

OTHER TYPES OF GEOMAGNETIC STORMS

The perturbations with gradual commencement do not, however, constitute an "exclusive" privilege of minimum type corona: it has been made clear that each time changes at the activity center have already taken place before the CM and have persisted, disturbances with gradual commencement regularly set in. Here again everything tends to make one believe that coronal plasma accumulations have penetrated in the proximity of the magnetosphere already in diffused state. The example of such a perturbation with gradual commencement lies in the storm of 6 and 7 October 1960. The Sun was observed at the Geophysical Institute of the Czechoslovakian Academy of Sciences on 5 October with the aid of a spectrohelioscope, the activity of a little center (D13 according to the Freiburg charts) was observed, where numerous surges have arisen. Because these events were observed directly at the center of the visible disk, the forecast was issued, according to which one should anticipate a geomagnetic storm on 6 and 7 October. Since, unfortunately, the observations performed during the preceding days were too few, we assumed, judging from the sudden changes that took place on 5 October, that we would be confronted with a SC. Only later, could we ascertain, upon receiving the results registered at foreign stations, that the conditions were assembled for the onset of a storm with gradual commencement (Bednářová-Nováková, 1966).

Moreover, it is possible to explain on the basis of the system of studies of relationships admitted by us between the geomagnetic storms and the solar activity, the annual variations of the geomagnetic field, and forecast their unfolding under given conditions a long time in advance.

While recurrent storms are linked with the appearance of a coronal formation of rather long duration (most often of an equatorial wing of corona minimum type), the so-called "sporadic" storms are characterized by a sudden appearance of coronal formations. Furthermore, here much more favorable conditions exist for the combination of positive and negative action, which is translated by a more frequent and successive variation of Earth-oriented coronal formations, with the space devoid of plasma. Thus, it stems therefrom that in the period prior and during the solar activity minimum, that is, during the appearance minimum of local fields, preliminary conditions are assembled for the appearance of recurrent perturbations, whereas during the period of appearance of an accrued number of sunspots, i. e., during the period when the situation of the magnetic fields in the Sun is more complex, one may expect more frequent variations of the external geomagnetic field.

CONCLUSIONS

In the current paper we limited ourselves to mention some typical cases of perturbations and storms, and also of geomagnetic quiet periods, in order to show how one should interpret the relationships between the solar and geomagnetic activities. Basing myself upon experience, I take the liberty to assert that it would be possible to predict by means of our method every geomagnetic storm, on the condition to have continually available the results of Sun's observations.

In conclusion, allow me to quote the sentence pronounced in 1936 by Professor Giorgio Abetti: " si crede intanto di poter concludere che qualche fenomeno e sempre visible sul Sole quando si notano perturbazione nel magnetismo terrestre...". What is important is to well determine the real causes. At times they may constitute sudden events, at other times, to the contrary, — a relatively stable regime. It is necessary to observe the Sun continuously or nearly so in order to be aware of changes of even very short duration. This can only be achieved on the basis of continued international cooperation.

Forecasts having bearing on the geomagnetic activity ought to be regularly published every day, for example, in the following form:

One may expect :

Date — geomagnetic quiet, Kp_{min}; ≤ 10.
Date — geomagnetic storm, Kp_{max}; ≥ 50; the SC will take place within the time interval from x to x + 8 or 10 hours.
Date — perturbation with gradual commencement, Kp_{max}; ≤ 40 etc.

One the condition of availability of a large number of observation data, it would yet be possible to improve this method of forecasting, namely where we are to determine with greater precision the time interval between the appearance of the event on the Sun and the SC of the geomagnetic storm. We temporarily compute with 28 hours + an 8 — 10 hour difference, but it would be useful to render this value more precise, based upon the results registered in this field by other observation posts.

***** THE END *****

Translated by ANDRE L. BRICHANT

on 11 - 12 May 1967

REFERENCES

Abetti G.	1936	*Ossni Mem. Oss. Astrofis. Arcetri* **24**, 19.
Allen C. W.	1944	*Mon. Not. R. Astr. Soc.* **104**, 307.
Bednářová-Nováková B.	1954	*Geophys. Sb. 1953*, NČSAV, 189.
Bednářová-Nováková B.	1956	*Geophys. Sb. 1955*, NČSAV, 135.
Bednářová-Nováková B.	1959	*Říše Hvězd* **40**, 193.
Bednářová-Nováková B.	1960	*Studia Geophys. Geod.* **4**, 52.
Bednářová-Nováková B.	1961	*Studia Geophys. Geod.* **5**, 138.
Bednářová-Nováková B.	1963	*Geophys. Sb. 1962*, NČSAV, 265.
Bednářová-Nováková B.	1964	*Geophys. Sb. 1963*, NČSAV, 383.
Bednářová-Nováková B.	1965	*Geophys. Sb. 1964*, NČSAV, 277.
Bednářová-Nováková B.	1966	*Studia Geophys. Geod.* **10**, 437.
Bell B. and Glazer H.	1957	*Smithson. Contr. Astrophys.* **2**, 54.
Bugoslavska E.	1949	*Publs. Sternberg Astr. Inst.* **19**.
Kiepenheuer K. O.	1946	*Naturwissenshaften* **33**, 119.
Kiepenheuer K. O.	1953	*Atti Conv. Acad. Lincei* **11**, 148.
Ness N. F. and Wilcox J. M.	1966	*Astrophys. J.* **143**, 23.
Pecker J. C. and Roberts W. O.	1955	*J. Geophys. Res.* **60**, 33.
Vsessiatsky S. and Bugoslavska E.	1939	*The Total Solar Eclipse of June 1936*, II, IAN, CCCR.
Waldmeier M.	1946	*Terr. Magn. Atmos. Elect.* **51**, 538.